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THE PEP-II INTERACTION REGION WITH THE BABAR SOLENOID[*]

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Abstract

In the spring of 1999, the BaBar detector rolled onto the beam line in the PEP-II[1] interaction region (IR). The presence of the detector solenoidal field significantly alters the behavior of the accelerator. Both beams, the high-energy beam (HEB) and the low-energy beam (LEB), are affected. The beams become coupled in the xy plane and the orbits are changed. We discuss these and other changes brought about by the solenoidal field of the BaBar detector.

1 THE INTERACTION REGION

The PEP-II interaction region[2], shown in figure 1, employs two strong horizontal bending magnets (B1) located ±21 cm from the IP to bring the beams into a head-on collision. On either side of the interaction point (IP), the beams also pass through a shared quadrupole (QD1) which is centered on the HEB. This design places the LEB off-axis in this defocusing quad which further horizontally separates the two beams prior to the beams entering separate vacuum chambers. The next three magnets on either side of the IP are septum quadrupole magnets where one of the beams travels through a field-free region while the other is focused either horizontally or vertically. The first of these magnets (QF2) is a focusing magnet for the LEB. QF2 and QD1 form the LEB final-focus doublet. The next two magnets (QD4 and QF5) are the final-focus doublet for the HEB; the shared QD1 magnet supplys additional vertical focusing for the HEB. Table 1 lists some design parameters related to the collision point.

The B1 bending magnets and the QD1 quadrupoles are made from permanent magnet material. This construction was necessary since these elements are inside the magnetic field of the detector. The permanent magnets are also very compact and thereby take up a minimum amount of premium space near the center of the detector.

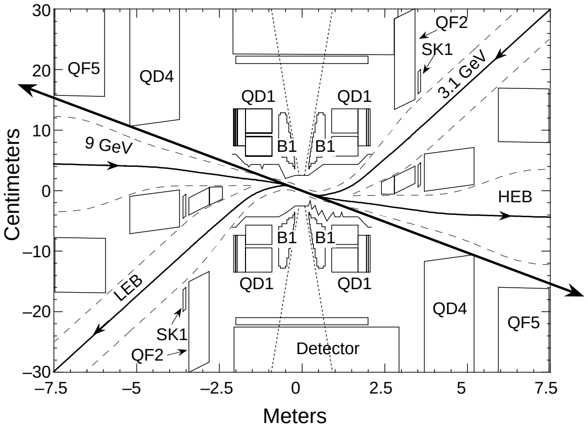

Figure 1. Layout of the interaction region. Note the expanded transverse scale. The large thick arrow leaving the IP denotes the direction of the radiative Bhabha photons used for measuring luminosity.

Table 1. PEP-II IP design parameters.

	HER	LER
Energy (GeV)	8.9732	3.1186
Current (A)	0.75	2.15
β_x^* (m)	0.50	
β_y^* (m)	0.015	
σ_x (μm)	155	
σ_y (μm)	4.7	
Σ_x (μm)= $\sigma_x \sqrt{2}$	220	
Σ_y (μm)= $\sigma_y \sqrt{2}$	6.6	
ξ_x and ξ_y	0.03	
Bunch spacing (m)	1.26	
Bunch luminosity ($cm^{-2}s^{-1}$)	1.8×10^{30}	
Total luminosity ($cm^{-2}s^{-1}$)	3×10^{33}	

2 THE BABAR DETECTOR FIELD

The BaBar detector field has a maximum field strength of about 1.5T producing a integrated strength of 6.12 T-m. The detector field is not parallel to the collision axis but is rotated about the y axis by −20.4 mrad with respect to the collision axis. Figure 1 is a layout of the beam orbits with respect to IR reference frame. The detector frame of reference is rotated +3.5 mrad in this frame which means the collision axis in Fig. 1 has an angle of −16.9 mrads. The −20.4 mrad detector angle was found to be optimal in reducing the overall amount of steering both beams experience when they traverse the detector field. Figure 2 shows the magnetic field strength along the detector axis. The detector is displaced 37 cm in the +z direction, the direction of the electrons and hence the direction of the boost, in order to improve detector acceptance.

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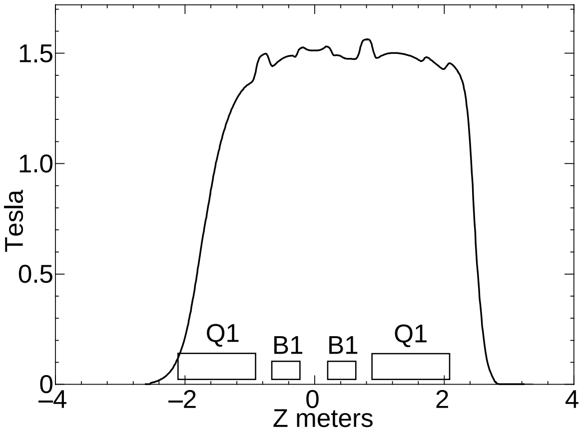

Figure 2. Field map of the magnetic field of the detector. The map is from a model of the detector that includes the permanent magnet material of the B1 and Q1 magnets.

3 COUPLING CORRECTION

Six skew quadrupoles located on either side of the collision point for each beam line are used to correct the coupling terms generated when the beams go through the detector solenoidal field[3]. The coupling of the LEB is much worse than that of the HEB. In addition, the LEB has a local chromaticity correction scheme that places sextupoles very close to the IP (12 m and 28 m) and the LEB starts ramping vertically back up to be above the HEB at 10 m from the IP. These extra requirements on the LEB considerably complicate the lattice functions just outboard of the IP making it all the more important to start correcting the coupling as soon as possible. In the case of the LEB, the correction starts right after the QF2 magnet. We have installed a relatively thin (4 cm on the -z side and 8 cm on the + z side) permanent magnet quadrupole (SK1) that can be rotated to generate a skew quad field. The strength of the QF2 septum magnet is adjusted to compensate for the change in the normal component of the rotated permanent magnet. The next skew quadrupole for the LEB is located at about 12 m from the IP, just before the first local sextupole. Figure 3 and figure 4 show a layout and side view of the beam lines in the region 2 straight section. In fact, for both beams, the first two skew quadrupoles of the compensation scheme are located after the final focus quadrupoles and before the next quadrupole in the lattice. For the HEB, this is easier to accomplish since the next quadrupole after the QF5 magnet is located 44 m from the IP.

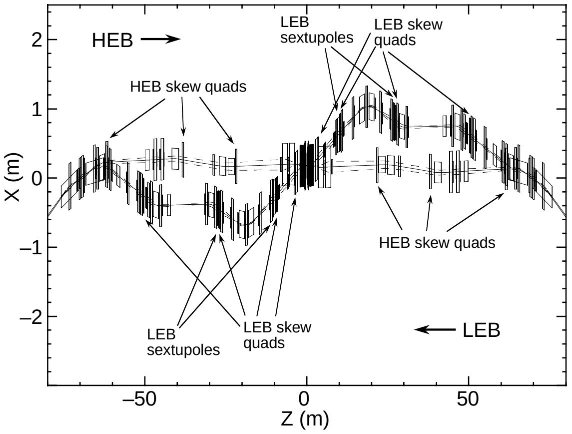

Figure 3. Layout of the beam lines of the rings in the region 2 straight. Note the exaggerated transverse scale. The location of the skew quads for both beams are shown as well as the sextupoles used in the local chromaticity correction for the LER. There are three more skew quads for the HEB on either side of the IP that are located in the nearby arcs. The last two HEB skew qudrupoles on each side are created by using closed orbit bumps to offset the beam in sextupoles. The remaining two LEB skew quads on each side of the IP are made by energizing extra windings on arc sextupoles.

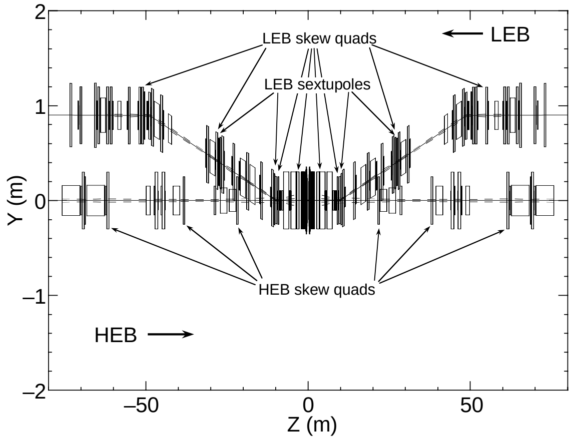

Figure 4. Side view of the beam lines in region 2 straight. The LEB starts ramping down at about 28 m from the IP and reaches the level of the HEB at 10 m from the IP. The compensating skew quadrupoles are located as close to the IP as possible for both beams, especially for the LEB.

4 THE INTERACTION REGION ORBIT

As mentioned earlier, the detector field significantly steers both beams. This is due to the changing trajectories of the beams since the strong B1 magnets are separating the beams horizontally. These changing horizontal trajectories are not parallel to the detector field and hence produce vertical forces on the beams. These vertical kicks must be corrected by vertical steering correctors, but the closest location for these correctors is ±5.4 m from the IP; too far away to recapture the beams. In order to lessen and balance the vertical kicks received by the beams, the horizontal angle of the detector field was considered a free parameter. The optimal value of −20.4 mrad with respect to the collision axis places the detector closer to the LEB final horizontal angle, thereby greatly reducing the kick received by that beam. Even so, the vertical kicks from the solenoid are still too much for the vertical correctors to fix, so the magnetic axis of the QD4 and QF2 magnets are displaced vertically to provide steering for the beams prior to entering the vertical correctors located ±5.4 m from the IP. In addition, another strong set of vertical correctors at ±9 m is used in the LEB to complete the vertical correction before entering the local sextupoles at ±10 m. Figure 5 shows a side view of the beam orbits as they go through the detector field, vertically offset magnets QD4 and QF2, and vertical correctors.

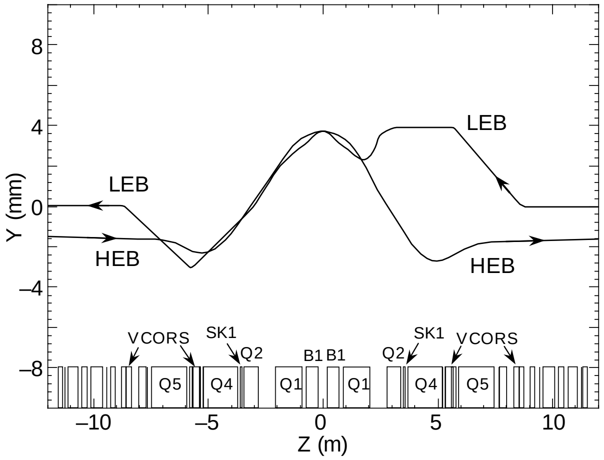

Figure 5. Side view of the orbits near the IP. The vertical orbit kick from the detector field is compensated in three ways: by optimizing the angle of the detector field, by vertically displacing the centers of the QF2 and QD4 magnets and by the use of vertical correctors (VCORS) located in each ring at about ±5.4 m from the IP.

5 ORBIT STABILITY

The skew quad settings for the coupling correction design depend very heavily on the orbit of each beam. For the HEB, the two outboard skew quadrupoles are generated by displacing the beam in sextupoles with closed bumps. The orbit of the LEB is even more important. If the beam is offset by more than 1 mm when it travels through the local sextupoles, significant skew terms arise from these sextupoles. In addition, changing the orbit of either ring as the beams travel through the detector field will also change the amount of induced coupling.

We observe orbit drifts in both rings that are dependent on the beam current as well as diurnal temperature changes in the interaction region. For this reason, we have implemented orbit feedback loops in each ring. We attribute the orbit drift to moving final focus quadrupoles in each ring. The feedbacks use a local corrector to resteer the beam near the IP and correct for the orbit drift.

At some level, adjusting the IP angle and position in order to get the beams into collision and to maximize luminosity alters the local orbit through the detector and thereby changes the coupling. In addition, the accelerator does not match the present design model. We attribute some of this mismatch to a small weakening (about 1%) of the permanent magnet elements located in the detector solenoidal field. This weakening affects the orbits through the detector and hence the coupling.

Since the machine does not perfectly match the design, a method of measuring local coupling and recalculating the skew quad settings has been developed[4]. The coupling is measured by turning on, for instance, an x corrector in a region far from the IP and looking at the orbit oscillation in the vertical plane induced by the horizontal wave generated by the x corrector. This process is then repeated in both planes for several different corrector phases.

The coupling at the IP can have a large impact on the luminosity. Since the design beam spots have a small beam aspect ratio (0.03 vertical/horizontal) a relative tilt or xy rotation between the beams of a little as 5 degrees can lower the luminosity by a factor of two[5]. As accelerator improvements are made that decrease the vertical size of the beam and move the size closer to the design value (or perhaps even smaller) controlling the coupling or tilt at the IP becomes more and more crucial.

6 SUMMARY

The detector solenoid is a major perturbation to both PEP-II beams, the low-energy beam much more than the high-energy beam. The coupling induced by the detector field affects many aspects of the accelerator, but especially the tilt or xy rotation of each beam at the interaction point. We have found that the coupling depends directly on the orbits of each beam in the detector and that orbit stability is an important part of effectively minimizing the spot size and maintaining a steady state at the collision point.

7 ACKNOWLEDGMENTS

We thank the PEP-II team and the BaBar detector team for all the work they did to make this accelerator and detector turn on so rapidly.

8 REFERENCES

[1] "PEP-II an Asymmetric *B* Factory", Conceptual Design Report, CALT-68-1869, LBL-PUB-5379, SLAC-418, UCRL-ID-114055, UC-IIRPA-93-01, June 1993.

[2] M. Sullivan, *et.al*. "Interaction Region Design at the PEP-II *B* Factory", pg. 460, EPAC 1996, June 1996

[3] Y. Nosochkov, *et.al*. "Detector Solenoid Compensation in the PEP-II B-Factory", pg. 585, PAC 1995, May 1995

[4] Y. Cai, "Beam Based Solenoid Compensation for the PEP-II", SLAC-PUB 8236, also in these proceedings

[5] J. Seeman, private communication.